INTERNATIONAL JOURNAL OF ADVANCES IN PHARMACY, BIOLOGY AND CHEMISTRY

Review Article

Insight into Nanotechnology and Applications of Nanomaterials

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ABSTRACT

The evolution of technology and instrumentation as well as its related scientific areas such as physics and chemistry are making the research on nanotechnology aggressive and evolutional.The ability to construct tiny objects atom by atom or molecule by molecule forms one of the exciting prospects of the research field in nanoscience. It shows great promise for providing us in the near future with many breakthroughs that will change the direction of nanotechnology advances in a wide range of applications. At the nanoscale dimensions, the material properties change significantly differing completely from their bulk counterparts. Nanomaterials display new phenomenon associated with the quantized effects and with the preponderance of surfaces and interfaces. Metal nanoparticle dispersions exhibit colors due to the surface plasmon resonance phenomenon, which is caused by the coherent oscillation of conduction band electrons when they interact with electromagnetic field. Carbon nano tubes contain two and more coaxial cylinders, respectively, with each cylinder being a single walled carbon nanotube with weak van der Waal forces binding the cylinders together. Many synthetic methodologies for zero and one dimensional nanostructures have been developed, including vapor phase methods and aqueous methods. Laser ablation has been extensively used for the preparation of nanoparticles and particulate films. The main aim of nanotechnology is to enhance productivity through nanotech driven precision farming and to maximize the output and minimize inputs through better monitoring and targeted.

Keywords: Nanoscience, Nanomaterials, Classification, Properties, Synthesis.

1. INTRODUCTION

The term "Nanotechnology" was first defined by Norio Taniguchi of the Tokyo Science University in 1974. Nanotechnology, shortened to "Nanotech", is the study of manipulating matter on an atomic and molecular scale. Generally nanotechnology deals with structures sized between 1 to 100 nm and involve developing materials or devices within that size. For comparison, 10 nanometers is 1000 times smaller than the diameter of a human hair. Nanotechnology has the capacity to improve our ability to prevent, detect and remove environmental contaminants in air, water and soil in a cost effective and environmentally friendly manner. Nanoscience and nanotechnologies are revolutionizing our understanding of matter and are likely to have profound implications for all sectors of the economy, including agriculture and food, energy production and efficiency, the automotive industry, cosmetics, medical appliances and drugs, household appliances, computers and weapons[1-3].This capability also simultaneously gives us the ability to build materials and devices or shapes and products on that scale. Because of the brevity in operation, smarter and lighter products can be made from the molecules of the same matter with every atom in its specified place through ‘positioned assembly’ or ‘self assembly’. The matter displays unimaginably different qualities when manipulated and structured at nanoscale. It produces different products when assembled at that scale. This is what is the future unleashed by the nanotechnology revolution.We have been stilldealing with the matter at a bigger scale. The building blocks, our engineering skills andproducts were bigger than the nanosize and hence had limitations in manipulation. It isthis arrangement of atoms which defines the properties of matter. With its capacity tomanipulate the smallest possible component of the matter, the nanotechnology has thepotential to bring that cycle of technological revolution to completion: dealing with thematter atom by atom, molecule by molecule. It is this capacity of mankind to deal withmatter at molecular level that will give the mankind a historical new ability to shape,process and create things which have never been thought of.

Nanotechnology, introduced almost half century ago, is one of the most active research areas with both novel science and useful applications that has gradually established it in the past two decades. The evolution of technology and instrumentation as well as its related scientific areas such as physics and chemistry are making the research on nanotechnology aggressive and evolutional. Not surprisingly, it is observed that expenditure on nanotechnology research is significant. The U.S. National Nanotechnology Initiative (NNI) expenditures exceed $1 billion each year, with the President's 2008 budget for NNI at $1.5 billion. However, the research is mainly moving forward motivated by immediate profitable return generated by high value commercial products[4].The branch of nanoscience and technology is trulymulti-disciplinary and is an emerging technology withfull of promises to have an impact on virtually everyspectrum of civilization including communications,computing, textiles, cosmetics, sports, therapy,automotives, environmental monitoring, fuel cells andenergy devices, water purification, food and beverageindustry, etc. The ability to construct tiny objectsatom by atom or molecule by molecule forms one ofthe exciting prospects of the research field in nanoscience. It shows great promise for providing us in thenear future with many breakthroughs that will changethe direction of nanotechnology advances in a widerange of applications[5-7].

Metal oxides play a very important role in many areas of chemistry, physics and materials science. The metal elements are able to form a large diversity of oxide compounds.These can adopt a vast number of structural geometries with an electronic structure that can exhibit metallic, semiconductor or insulator character. In technological applications, oxides are used in the fabrication of microelectronic circuits, sensors, piezoelectric devicesand fuel cells, coatings for the passivation of surfaces against corrosionand as catalysts. In the emerging field of nanotechnology, a goal is to make nanostructures or nanoarrays with special properties with respect to those of bulk or single particle species. Oxide nanoparticles can exhibit unique physical and chemical properties due to their limited size and a high density of corner or edge surface sites. Particle size is expected to influence three important groups of basic properties in any material. The first one comprises the structural characteristics, namely the latticesymmetry and cell parameters. Bulk oxides are usually robust and stable systems with well-defined crystallographic structures. However, the growing importance of surface free energy and stress with decreasing particle size must be considered, changes in thermodynamic stability associate with size can induce modification of cell parameters and structural transformations and in extreme cases the nanoparticle can disappear due to interactions with its surrounding environment and a high surface free energy. In order to display mechanical or structural stability, a nanoparticle must have a low surface free energy. As a consequence of this requirement, phases that have a low stability in bulk materials can become very stable in nanostructures. This structural phenomenon has been detected in TiO_2, VO_x, Al_2O_3 or MoO_x oxides[8-10].Cobalt-based nanoparticles reside between the most promising materials for technological applications like information storage, magnetic fluids and catalysts. The low crystal anisotropy of cobalt also promotes their study them as a model system for the effects of size, shape, crystal structure and surface anisotropy on their macroscopic magnetic response. A variety of methods to the preparation of cobalt colloid dispersions has been reported. The most commonare the reduction of a cobalt salt and the thermal decomposition of a cobaltcarbonyl[11, 12].

2. PROPERTIES OF NANOMATERIALS

At the nanoscale dimensions, the material properties change significantly differing completely from their bulk counterparts. Nanomaterials display new phenomenon associated with the quantized effects and with the preponderance of surfaces and interfaces. The quantization effect arises in nanometer regime because the overall dimensions of objects are comparable to the characteristic wavelength of fundamental excitations in materials.As the size of material decreases, the percentage of surface atoms increases, thus increasing the reactivity and making them highly reactive catalysts, as surface atoms are the active centers for elementary catalytic processes. For example, iron nanoparticles of sizes 3 nm, 10 nm and 30 nm will have 50%, 10% and 5% of atoms on surface. Among the surface atoms, atoms sitting on the edges and corners are more reactive than those in planes. Also, the percentage of atoms at the edges and corners increases with decrease in the particle size and therefore, smaller metal particles are preferred for catalysis. An interesting feature of metal and semiconductor nanoparticles is their optical property. These nanomaterials exhibit interesting shape and size dependent optical properties due to quantum confinement. However, in a bulk crystal, the properties of material depend on chemical composition and not on size. Due to the decrease in size of a crystal towards nanometer regime, the electronic structure is altered from continuous electronic bands to discrete or quantized electronic levels. Therefore, the continuous optical transitions between the electronic bands become discrete and the properties of nanomaterial become size dependent[13].

Metal nanoparticle (Au, Ag and Cu) dispersions exhibit colors due to the surface plasmon resonance (SPR) phenomenon, which is caused by the coherent oscillation of conduction band electrons when they interact with electromagnetic field. During SPR, polarization of the electrons with respect to the much heavier ionic core is induced by the electric field of an interacting light wave. This creates a net charge difference at nanoparticle surface, which acts as a restoring force. Thus, a dipolar oscillation of all the electrons with the same phase is created. The so observed color originates from the strong absorption by the metal nanoparticles when the frequency of electromagnetic field becomes resonant with the coherent oscillation of electron motion. The frequency and width of SPR depends on the metal nanoparticle size, shape, dielectric constant of the metal itself and the surrounding medium. Similarly, other important properties such as electronic properties, magnetic properties, melting point and catalytic properties of the nanomaterials depending on their shape, size, composition and surrounding medium have been studied in great detail[14].

Another most important property of nanomaterials, especially semiconductor nanoparticles, is to exhibit photocatalytic behavior. Size dependent properties (quantization) of semiconductors (such as TiO_2 and ZnO etc.) and quantized charging effects in metal nanoparticles provide the basis for developing new and effective systems. These nanostructures provide innovative strategies for designing next generation energy conversion devices. In a semiconductor, the energy difference between the valence band and the conduction band is known as the "Band Gap". When it absorbs radiation from sunlight or illuminated light source, it generates pair of electron and hole. This stage is known as the semiconductors, photo-excitation state. The recombination of electron-hole pair may result in light emission with appropriate further reactions. These semiconductors behave as photo catalysts[15].Nanotechnology has created a kind of revolution as this new area encompasses physics, chemistry, materials science and engineering and also biology and medicine. Several applications are envisaged from these interesting materials in the field of sensors, catalysis, diagnostic tools, therapeutic agents, drug/gene delivery vehicles, solar cells, plasmonics devices, cosmetics, coating materials, cell imaging, fuel cells, photonic band gap materials, single electron transistors, non-linear optics devices and surface enhanced Raman spectroscopy[16].

Two principal factors cause the properties of nanomaterials to differ significantly from other materials:increased relative surface area and quantum effects. To understand the effect of particle size on surface area, consider a U.S. silver dollar. The silver dollar contains 26.96 grams of coin silver, has a diameter of about 40 mm and has a total surface area of approximately 27.70 square centimeters. If the same amount of coin silver were divided into tiny particles - say 1 nanometer in diameter, the total surface area of those particles would be 11,400 square meters. When the amount of coin silver contained in a silver dollar is rendered into 1 nm particles, the surface area of those particles is 4.115 million times greater than the surfacearea of the silver dollar![17].

Electrical properties: The electrical properties of nanomaterials vary betweenmetallic to semiconducting materials. It depends on thediameter of the nanomaterials. The very high electricalconductivity of nanomaterial is due to minimumdefects in the structure.

Thermal conductivity: The thermal conductivity of nanomaterials are veryhigh, is due to the vibration of covalent bonds. Itsthermal conductivity is 10 times greater than the metal.The very high thermal conductivity of nanomaterial isalso due to minimum defects in the structure.

Mechanical properties: Nanomaterials are very strong and withstand extremestrain. Most of the materials fracture on bendingbecause of the presence of more defects, butnanomaterials possesses only few defects in thestructure[18].

3. CARBON NANOSTRUCTURE - PROPERTIES AND APPLICATIONS

Single walled carbon nanotubes (SWCNT) form a hexagonal network of carbon atoms rolled into a seamless, hollow cylinder, with each end capped with half a fullerene molecule. Rolling of the graphene sheet at different angles creates a visible twist or spiral in the molecular structure, giving it chiral properties. The basic structure of a SWCNT is specified by a single vector called the chiral vector Ch. As shown in Fig. 1, this vector is denoted by OA and is the section of the nanotube perpendicular to the nanotube axis, which when rolled up is the circumference of the tube. Fig. 1 shows the unrolled lattice of the nanotube and, in this case, the direction of the nanotube axis is given by the vector OB. The lattice can then be rolled to form a cylinder by lining up the points so that O is on top of A and B is on top of B'[19].Carbon nano tubes (CNT) can be found in other forms, for example the double walled carbon nanotubes (DWCNT) (Fig. 2b) and multi walled carbon nanotubes (MWCNT) (Fig. 2a and2c). DWCNT and MWCNT contain two and more coaxial cylinders, respectively, with each cylinder being a SWCNT with weak van der Waal forces binding the cylinders together.

Carbon nanofiber (CNF) is characterized by a graphitic like structure with variable alignments of laminated hexagon layers along the fiber axis. The graphitic platelet sheets that make up the nanofiber can be mainly divided into three different configurations, as shown in Fig. 3. Fig. 3b shows that the graphitic layers are at an angle to the fiber axis and this is usually called the herringbone or cup stacked structure due to its shape. In the final configuration, graphitic layers are positioned perpendicular to the fiber axis and are stacked on top of each other(Fig. 3c)[20].Due to their remarkable properties, CNTs have been investigated for various applications such as light emitting diodes, sensors, actuators, logic circuits, super capacitors, filters and ceramic and reinforced composites. CNFs are used in fuel cells, super capacitors sensors and tissue engineering and composite applications[21].

Electrostatic force microscopy (EFM) has been widely used to investigate electrostatic properties of nanomaterials. In EFM experiments, an AC bias voltage with frequency ω is applied between a conducting atomic force microscope (AFM) probe and the sample. A lock-in amplifier at the same AC frequency ω is used to detect interaction forces between the tip and the electrostatic field due to static charges and permanent dipole moments of the sample. In addition, a dipole moment in the sample induced by the AC bias voltage also interacts with the tip. This dielectric force oscillates at the double frequency and is thus detected using a separate lock-in amplifier at the 2ω frequency. The electrostatic force channel in EFM has been utilized in investigating nanometer-scaled distribution of charge and electric dipole moment, surface potential variation, charge storage, and leakage in materials and devices.The 2ω channel in EFM has also been utilized to measure the equivalent dielectric constant of individual SWCNT[22].

4. SYNTHESIS OF NANOMATERIALS

Nanomaterials can be synthesized by any one of the following methods

Pyrolysis: It involves pyrolysis of hydrocarbons such asacetylene at 7000C in the presence of Fe-silica or Fegraphitecatalyst under inert conditions.

Carbon arc method: It is carried out by applying direct current (60-100 A and 20-25 V) arc between graphite electrodes of10-20μm diameter.

Laser evaporation method: It involves vapourisation of graphite containingsmall amount of Co and Ni, by exposing it to laserbeam at 12000C in a quartz tube reactor. An inert gaslikeargon is allowed to pass into the reactor to sweepthe evaporated carbon atoms from thefurnace to thecopper collector, on which the nanomaterials condense.

Chemical vapour deposition: It involves decomposition of vapour ofhydrocarbons such as methane, ethylene, acetylene,etc., at 11000C in presence of catalysts like Ni, Co, Fesupported on MgO.Fig. 4 shows theschematic outlines of the various approaches for the synthesis of nanoparticles[23].

Combustion synthesis (CS) or self-propagating high-temperaturesynthesis (SHS) is an effective, low-cost method for productionof various industrially useful materials. Today CS hasbecome a very popular approach for preparation of nanomaterialsand is practised in65 countries. Recently, a number of importantbreakthroughs in this field have been made, notably for developmentof new catalysts and nanocarriers with properties better thanthose for similar traditional materials. The extensive research carriedout in last five years emphasized the SHS capabilities for materialsimprovement, energy saving and environmental protection.The importance of industrialization of the SHS process is also realized.All these aspects were adequately brought out and discussedin the international conference devoted to the 40th anniversary ofSHS, which was held at ISMAN (Chernogolovka, Russia) in October2007[24].Nanostructured ZnO materials have drawn broad attention due to its wide range of applications in ultraviolet (UV) lasers, power generators,solar cells, gas sensors, field emission devices, capacitors, varistors, transparent UV resistance coating, photoprinting, electrophotography, electrochemical and electromechanical nanodevices, sun screen lotion (cream), cosmetic and medicated creams etc. Some of the future applications include catalysts for organic reactions and delivering drugs to infected areas of body.

Many synthetic methodologies for zero and onedimensional ZnO nanostructures have been developed, including vapor phase methods and aqueous methods.The vapor-phase method usually employs vacuum, sophisticated equipment and elevated temperature which restrict the type of substrate used, in contrast to the low-cost and simple aqueous methods. However, simple methods for preparation of high quality nanostructures with high yield and good control on shape and size are very less. Among the aqueous methods, the hydrothermal method has emerged as a powerful method for the fabrication of one-dimensional nanomaterials with some significant advantages, such as controllable structures and a cost effective, low-temperature, substrate independent and less complicated technique. However, yield and quality of the product material is usually not addressed. For example, Kale et al. reported synthesis of high-yield of flowerlike ZnO nanorods using a hydrothermal method[25]. However, near band edge UV emission was not observed from those samples due to poor quality of the material and large defect concentration. Similarly, large-scale synthesis of ZnO flower-like and brush pen-like nanostructures by a hydrothermal decomposition route showed very weak UVemission and strong green emission[26]. In majority of the studies, the product suffers from poor optical properties due to presence of large concentration of intrinsic defects in ZnO. Chu et al recently reported a solution-based, high yield synthesis of cobalt-doped ZnO nanorods with roomtemperature ferromagnetism[27].However, the reported studies have product yield below 50%. Hence, large scale and high yield synthesis of defect free ZnO nanostructures is imperative to meet the demand for emerging applications[28].Cuprous iodide (CuI) has attracted much attention because of its unusual feathers such as large band gap, a negative spin-orbit splitting, an unusually large temperature dependency, anomalous diamagnetism behavior, large ionicity, new high pressure phase etc. and potential applications in superionic conductor, solid-state solar cells, catalysis for synthesis of organic compounds and others. Nano size CuI is being pursued with great interest because of several possible technical applications in catalysis, drug delivery systems, separation techniques, photonics as well as piezoelectric and other dielectric devices[29].

Fluorescent nanoparticles have attracted increasing researchattention due to their promising applications covering electroopticsto bionanotechnology. To date, typical photo luminescentparticles have been developed from compounds oflead, cadmium and silicon. But these materials also haveraised concerns over potential toxicity, environmental harmand poor photostability. The need for photoluminescentnanostructures emitting in visible-to-near infrared (NIR)spectral range is rapidly increasing. Compared toconventional measurements made in the ultravioletvisible region, spectrofluorimetrywithin the therapeutic windowof 700-1200 nm has many advantages, such as lower levels ofbackground interference and deeper penetration of living tissues. NIR photoluminescence (PL) obtained from NIRexcitation holds great promise for in vivo uses at significantdepths in biological media and the development of noninvasivediagnostic techniques. Consequently, an excellent fluorescent nanoparticle for bio applications should be more stable, and less toxic as well as exhibit good NIR emission. Compared to traditional quantum dots (QDs) and organic dyes, photo luminescent carbon nanomaterials are superior in chemical inertness and likely lower toxicity. The emergence of photo luminescent carbon-based nanomaterials has presented exciting opportunities for searching for fluorescent nanomaterials. Moreover, the up-conversion nanomaterials for biological luminescent labels also have attracted great attentions due to their unique luminescent properties with long lifetime and superior photo stability. In comparison with down conversion fluorescent materials, up-conversion materials have many advantages in biological applications, such as noninvasive and deep penetration of NIR radiation, the absence of auto fluorescence of biological tissues, and feasibility of multiple labeling with different emissions under the same excitation. A recent study indicated that core-shell structured CNPs have two-photon active luminescence with excitation in the NIR range. Thus, we can expect that carbon-based fluorescent nanoparticles may possess visible, NIR, and up-conversion luminescence synchronously, which are extremely important for fundamental and practical applications[30].

5. NANOCRYSTALS

Nanocrystals are zero-dimensional particles and can be prepared by several chemical methods, typical of them being reduction of salts, solvothermal synthesis and the decomposition of molecular precursors, of which the first is the most common method used in the case of metal nanocrystals. Metal oxide nanocrystals are generally prepared by the decomposition of precursor compounds such as metal acetates, acetylacetonates and cupferronates in appropriate solvents, often under solvothermal conditions. Metal chalcogenide or pnictide nanocrystals are obtained by the reaction of metal salts with a chalcogen or pnicogen source or the decomposition of single source precursors under solvothermal or thermolysis conditions. Addition of suitable capping agents such as long-chain alkane thiols, alkyl amines and trioctylphosphine oxide (TOPO) during the synthesis of nanocrystals enables the control of size and shape. Monodisperse nanocrystals are obtained by post-synthesis sizeselective precipitation[31].Solid metallic nanoparticles are well-known for their attractive optical properties, strong optical resonance and a large and fast nonlinear optical polarizability associated with the Plasmon frequency of the conduction electron in the particle.Colloidal metal shells on the other hand can have resonance that can be tuned over a wide range as a function of the core-to-shell ratio. The greatly enhanced ability to manipulate the boundary conditions of the resonating conduction electrons makes it possible to cover theoretically the ultraviolet, visible and infrared parts of the spectrum. Westcott et al. have shown in several papers how such shells composedof gold can be grown around silica colloids and how the single particle properties can be exploited. Silica colloids provide for a convenient dielectric core as they can be grown with a small polydispersity[32].

6. EXAMPLES OF WHERE NANOTECHNOLOGY IS BECOMING USED

Nanowire and nanotube arrays for EMI shielding: Composite materials with superior thermal, electrical and mechanical properties, metal and semiconductor nanowires as tags forbioassays, etc. Carbon nanotubes, seamless tubes of graphite sheets of nanosized diameter, include SWCNT and MWCNT. In some cases, the ends of the nanotubes are open,whereas in other cases they are closed off with full fullerenecaps. Depending on sheet direction and diameter a nanotubemay be either metallic or semi-conducting. Compared with allother kinds of natural materials, carbon nanotubes have the highesttheoretical strength, although their specific gravity is onlyone-sixth of steel. Carbon nanotubes provide special advantagesin shielding and absorbing electromagnetic radiation, fieldemission, thermal conductivity, hydrogen storage, adsorption,catalyzing, etc.

Chemical gas sensing: Robust low power micro sensors and micro sensor arrays with high sensitivity and selectivity, such as humidity sensors, solid state resistive sensors, combustible gas sensors, etc.

Ceramic MEMS:2D and 3D micro components and micro electromechanical devices for harsh application environments, high aspect ratio MEMS, micro channel plates, etc.

Energy conversion: Photo-voltaics, radiation detection, electroluminescent andlasing materials and devices, components for mesoscopic energysources, etc.

Electronics and related fields: Scanning probes and scanning microscopy standards, storage media and Terabit memory, flat panel displays, vacuummicroelectronics for harsh environments, field emission cathodes,photonic band gap materials and devices, etc.

Marine anti-fouling: Due to the small size of the nanomaterials, the particles are held in the coating lattice and are not readily leached out of the coating by the marine environment, while slowly releasing ions to help provide longer-term anti-fouling character. The need for longevity of antimicrobial activity in marine environments is widely recognized.

Semiconductor polishing: As the semiconductor industry continues to move forwardto smaller chip architecture, the need for advanced CMP slurriesbecomes a requirement that cannot be met by the slurriesprovided in the past. Currently fumed silica and colloidal silicaare being used. Both of these are nanoparticles used for severaldecades already. New types are being developed now includingceria, mixed rare earth metal oxides and alumina dispersionswhich are on the forefront of providing high planarity surfacesand efficient removal rates. The unique surface chemistry ofthese nanomaterials allows formulation of highly concentrateddispersions at a variety of pH. Cabot is another leader developingproducts for this market.

Sunscreen formulations: Nanomaterials can act as sun blockers to protect human skinin formulations that go on smooth, silky and clear. Eliminatingunnecessary exposure to the harmful UV rays of the sun hasincreasingly become a key health concern.

Catalysts: The use of nanomaterials based on rare earth metal oxidesallows for the preparation of thinner active layers, which canmean less precious metal usage. These nanomaterials also allowfor the preparation of higher solids dispersions that are verystable, minimizing the number of coating steps and lossesdue to flocculated dispersions. Automotive catalytic convertersare a key focus area for catalyst performance. One way toachieve lower emissions in a cost effective manner is to utilizeco-catalysts that provide good oxygen storage capability andthermal stability in thinner layers. Nan ceria and mixed rareearth metal oxides meet the criteria necessary to enhance catalyticconverter performance when properly incorporated intoa catalyst system, and because they are dense, single phaseindividual crystals, there is nothing to collapse during thermalcycling[33].

7. CONCLUSIONS

Nanoscience refers to the science & discipline and nano technology refers the applied part of it including the engineering to control, manipulate and structure the matter at an unimaginably small scale: nano scale. Nanotechnology is one of the most active research areas with both novel science and useful applications that has gradually established it in the past two decades. Expenditure on nanotechnology research is significant; however, the research is continuously moving forward motivated by immediate profitable return generated by high value commercial products. The mankind has seen several technology revolutions in the past: industrial, agricultural, medical and infotech in a course of two centuries. Chemical sensors from nanoparticles and nanowires enhanced the sensitivity and sensor selectivity. The main aim is to enhance productivity through nano tech driven precision farming and to maximize the output and minimize inputs through better monitoring and targeted.

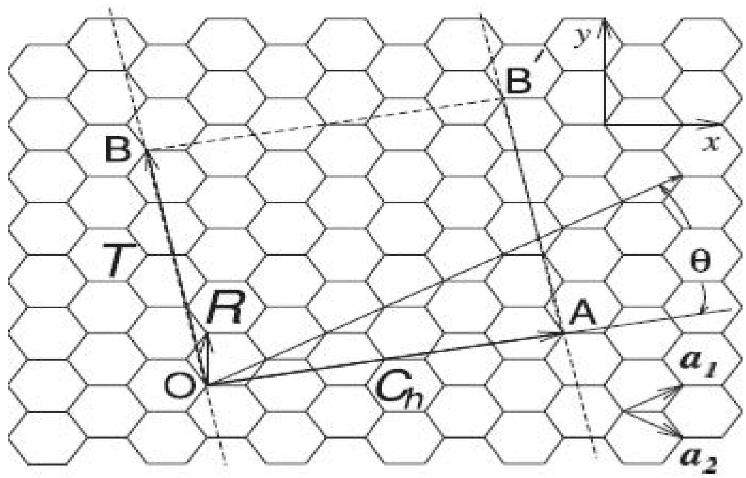

Fig. 1: Chirality in nanotubes

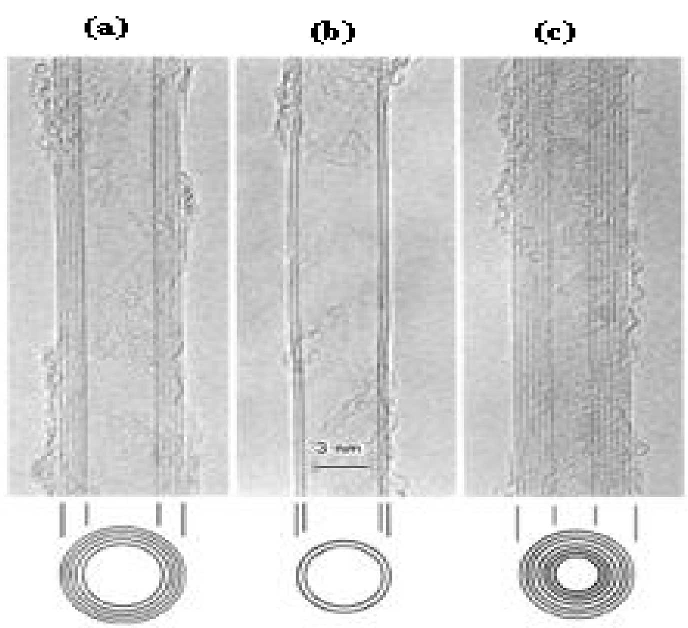

Fig. 2:(a) MWCNT (b) DWCNT and (c) MWCNT

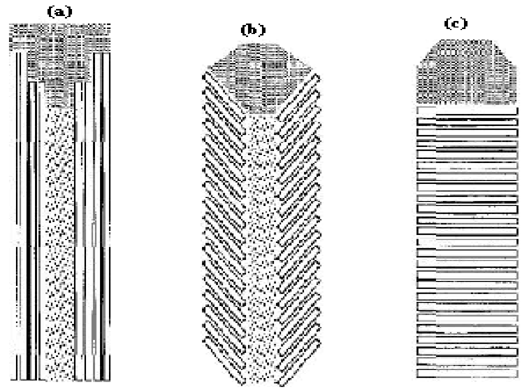

Fig. 3: Schematic representation of various arrangements of graphitic platelets in carbon nanofibers (a) tubular (b) at angle and (c) perpendicular to the fiber axis

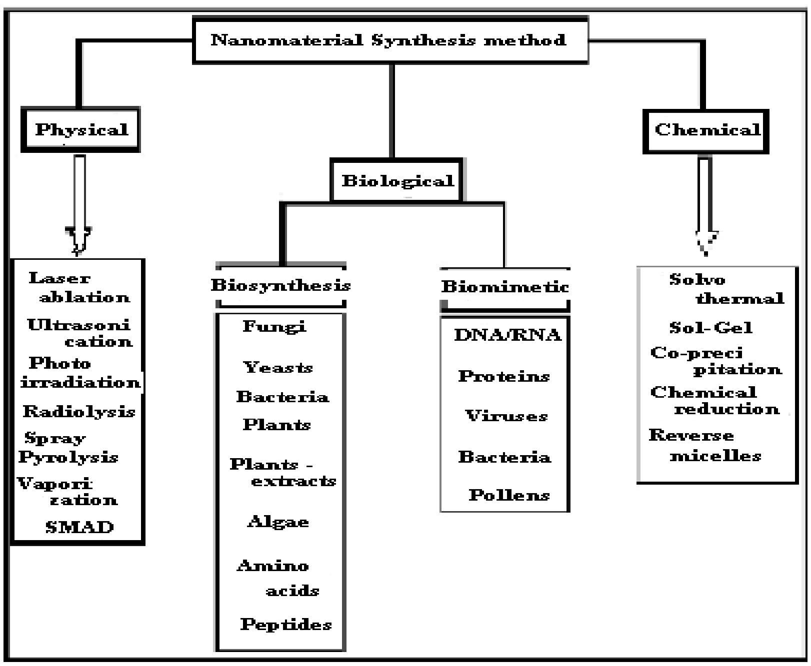

Fig. 4: Schematic outlines of the various approaches for the synthesis of nanoparticles

ACKNOWLEDGEMENTS

The Corresponding author (M. C. Rao) is thankful to UGC for providing the financial assistance through Major Research Project (Link No. F. No. 40-24/2011(SR))

REFERENCES

1. Varma R S, Saini R K, Dahiya R, Active manganese dioxide on silica: Oxidation of alcohols under solvent free conditions using microwave, Tetrahedron Lett., 1997; 38; 7823.
2. Kidwai M, Sapra P, Org. Prep. Proc. Int., 2001; 33; 381.
3. Gedye R, Smith F, Westaway K, Ali H, The use of microwave-ovens for rapid organic-Synthesis, Tetrahedron Lett., 1986; 27; 279.

4. Dhir R K, Newlands M D, Csetenyi L, J. Proc. Int. Conf., Appl. Tech. in Concrete Design, Scotland, UK, 2005.
5. Rajkumar N, Umamaheswari D, Ramachandran K, Int. J. Nano Sci., 2010; 9; 243.
6. Loupy A, Microwaves in Organic Synthesis, Wiley-VCH, Weinheim, 2002.
7. Lidstrom P, Tierney J, Wathey B, Nano materials and its potential applications, Tetrahedron, 2001; 57; 7764.
8. Noguera C, Physics and Chemistry at Oxide Surfaces, Cambridge University Press, Cambridge, UK, 1996.
9. Fernandez-Garcia M, Martinez-Arias A, Hanson J C, Rodriguez J A, Comparative study on redox properties of nanosized CeO_2 and CuO/CeO_2 under CO/O_2, J. Chem. Rev. 2004; 104; 4063.
10. Song Z, Cai T, Chang Z, Liu G, Rodriguez J A, Hrbek J, Molecular level study of the formation and the spread of MoO3 on Au(111) by scanning tunneling microscopy and X- ray photoelectron spectroscopy,J. Am. Chem. Soc., 2003; 125; 8060.
11. Puntes V F, Krishnan K, Alivisatos A P, Colloidal nanocrystal shape and size control: the case of cobalt, Science, 2001; 291; 2115.
12. Lu A H, Salabas E L, Schüth F, Magnetic nanoparticles: synthesis, protection, functionalization, and application, Angew. Chem. Int. Ed., 2007; 46; 1222.
13. Alivisatos A P, Perspectives on the physical chemistry of semiconductor nanocrystals, J. Phys. Chem., 1996; 100; 13226.
14. Qu J R, Hu M A, Chen J Z, Han W, J. China Univ. Geosci., 2005; 30; 195
15. Jensen T, Kelly L, Lazarides A, Schatz G C, Synthesis and Optical Properties of Anisotropic Metal Nanoparticles, J. Cluster Sci., 1999; 10; 295.
16. Kamat P V, Photophysical, Photochemical and Photocatalytic Aspects of Metal Nanoparticles, J. Phys. Chem. B, 2002; 106; 7729.
17. Dresselhaus M S, Dresselhaus G, Saito R, Carbon, 1995; 33; 88391.
18. Rodriguez N M, Chambers A, Baker R T K, Langmuir, 1995; 11; 38626.
19. Baughman R H, Zakhidov A A, de Heer W A, Carbon nanotubes-the route toward applications, Science, 2002; 297; 787.
20. Downs W B, Baker R T K, Nanostructured carbon for advanced applications, J. Mater. Res., 1995; 10; 625.
21. Bessel C A, Laubernds K, Rodriguez N M, Terry R, Baker K, Graphite Nanofibers as an Electrode for Fuel Cell Applications, J. Phys. Chem. B, 2001; 105; 1115.
22. Lu W, Zhang J, Stephanie Li Y, Chen Q, Wang X, Hassanien A, Chen L, J. Phys. Chem. C, 2012; 116; 7158.
23. Wong S, Harper J D, Lansbury P T, Lieber C M, Carbon Nanotube Tips: Biological Systems, J. Am. Chem. Soc., 1998; 120; 603.
24. Singanahally T, Aruna A, Alexander S, Mukasyan B, Combustion synthesis and Nanomaterials, Curr. Opinion in Solid State Matt. Sci., 2008; 12; 44.
25. Kale R B, Hsua Y J, Lina Y F, Lu S Y, Synthesis of stoichiometric flowerlike ZnOnanorods with hundred per cent morphological yield, Solid State Commun., 2007; 142 ; 302.
26. Bai W, Yu K, Zhang Q, Xu F, Peng D, Zhu Z, Large-scale synthesis of ZnO flower-like and brush pen-like nanostructures by a hydrothermal decomposition route, Mater. Lett., 2007; 61; 3469.
27. Chu D, Zeng Y, Jiang D, J. Am. Ceramic Soc., 2007; 90; 2269.
28. Giri P K, Bhattacharyya S, Chetia B, Singh K, Iyer P K, J. Nano sci. & Nanotech., 2011; 11; 1.
29. Rafie Johan M, AzriKhalisahAznan N, Synthesis and Characterization of Copper (I) Iodide Nanoparticles via Chemical Route, Int. J. Electrochem. Sci., 2012; 7; 4942.
30. Haitao L, Xiao die H, Yang L, Huang H, Suoyuan L, Shuit-Tong L, Kang Z, One-step ultrasonic synthesis of water-soluble carbon nanoparticles with excellent photoluminescent properties, Carbon, 2011; 49; 605.
31. Rao C N R,Vivekchand S R C, Govindaraj A, Synthesis of inorganic nanomaterials, Dalton Trans., 2007; 3729; 3728.
32. Westcott S L, Oldenburg S J, Lee T R, Halas N J, Formation and Adsorption of Clusters of Gold Nanoparticles onto Functionalized Silica Nanoparticle Surfaces, Langmuir, 1998; 14; 5396.
33. Deepika K, Suchita K, Kulkarni S K, Synthesis and characterization of silica–gold core-shell (SiO_2@Au) nanoparticles, J. Phys., 2007; 69; 277.